NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE AUTHOR(S)

Northwest Atlantic Fisheries Organization

**Serial No. N6044** **NAFO SCR Doc. 12-020**

**SCIENTIFIC COUNCIL MEETING – JUNE 2012**

**Biological Reference Points for Cod 3NO**

Fernando González-Costas and Diana González-Troncoso
fernando.gonzalez@vi.ieo.es

Instituto Español de Oceanografía, Apartado 1552, 36200 Vigo, Spain

## Abstract

In 2011 Fisheries Commission Working Group of Fishery Managers and Scientists on Conservation Plans and Rebuilding Strategies (WGFMS-CPRS) reviewed the cod 3NO Conservation Plan and Rebuilding Strategy (CPRS) and proposed a new one that was approved by the Fisheries Commission in 2011. The new reference points values approved for the 3NO cod CPRS were the following: $B_{lim}$ = 60,000 t, $B_{isr}$ = 120,000 t, $F_{lim}$ = 0.30 and $B_{msy}$ = 248,000 t. Concerns were raised on the high uncertainty and the lack of confidence intervals of the reference points. The WGFMS-CPRS agreed that the values of $B_{isr}$ and $B_{msy}$ should be further reviewed by the Scientific Council and the Fisheries Commission.

The aim of this document is to revise the approved Fisheries Commission reference points values and provide their confidence intervals. The YPR reference points ($F_{max}$ and $F_{0.1}$) were estimated and as well as the Spawning per Recruit (SPR) reference points for $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ of the SSB unfished level. For these reference points, biological uncertainty was incorporated in growth, maturation and in the fishery through variability in the partial recruitment. To incorporate the uncertainty, a bootstrap with 1000 iterations was carried out over the years to the whole period (1959-2009). Maturity, partial recruitment, stock and catch weights were bootstrapped together from the selected year range. The process of calculating the appropriate Maximum Sustainable Yield (MSY) reference points estimates was based on combining the yield per recruit analysis and the stock recruit relationship. Three stock-recruitment models were analyzed: Beverton-Holt, Ricker and Segmented Regression. To include uncertainty in the stock recruitment relationships it was chosen a non-parametric bootstrap.

Results show that the uncertainty is bigger for the references points estimated with S/R relationship than the YPR and SPR reference points as we can expected. The lack of fit of the S/R relationships is one of the mayor problems in 3NO cod. All the functions analyzed have clear fit problems: residuals pattern, big errors autocorrelation, not log normal distribution of the errors, problems in the likelihood profiles for the fit parameters and the maximum of the functions are not defined in the observed SSB range. Due to these problems it was proposed to use YPR a SPR reference points as proxies of the MSY reference points in 3NO cod. It could be recommended the use of $F_{max}$ (0.30) as proxy of $F_{msy}$ and $F_{lim}$ and as $B_{lim}$ a biomass level corresponding to the equilibrium $F_{max}$, around 60,000-70,000 tons. It could be proposed a value around $F_{0.1}$ (0.195) as a possible $F_{target}$. A reasonable $B_{target}$ could be a value in the upper probability range of the $F_{0.1}$ equilibrium Biomass (120,000 t). A good candidate for $B_{isr}$ could be 91,000 t. which is the level of biomass that has the 20% of the probability if we fish with $F_{0.1}$=$F_{target}$.

## Introduction

The NAFO Fisheries Commission formally adopted a Precautionary Approach (PA) framework in 2004 (NAFO/FC Doc. 04/17) as proposed by NAFO Scientific Council (NAFO SCS Doc. 03/23). The SC framework provides a structure that included limits, buffers, targets and management strategies that would adjust fishing mortality to keep stocks in the Safe Zone.

The 3NO cod is managed by NAFO. The 3NO Atlantic cod (*Gadus morhua*) stock collapsed in the early-1990s, and was placed under moratoria on directed fishing in 1994. Spawning Stock Biomass (SSB) has been since then near its minimum levels with some increase recently (Power *et al.*, 2010). In 2007 NAFO adopted a Conservation Plan and Rebuilding Strategy for 3NO cod (CPRS) that identified a limit reference point of 60,000 t.

In 2011, NAFO Scientific Council discussed the 3NO cod reference points based on the results of the study presented by Shelton and Morgan, 2011. This study used the stock recruitment (S/R) data for 3NO cod from the most recent assessment (Power *et al.*, 2010). Six different S/R models were fit to these data. While no particular S/R approach is strongly supported by the data, the authors chose the Loess smoother fitted to log recruitment as the base for deriving reference points. The references points were estimated through simulation by running the population to equilibrium with the dynamics determined by the S/R relationship, together with weights, maturity and partial recruitment vectors. Scientific Council notes that the available data for 3NO cod do not span the entire production curve and therefore large uncertainty in the estimated reference points can be expected (NAFO SCS Doc. 11/16).

The 3NO Cod CPRS was first adopted by the Fisheries Commission in 2007 and in force since 2008 (NAFO/FC Doc. 07/24). In 2011 Fisheries Commission Working Group of Fishery Managers and Scientists on Conservation Plans and Rebuilding Strategies (WGFMS-CPRS) reviewed the 3NO cod CPRS and proposed a new one that was approved by the Fisheries Commission in 2011 (NAFO/FC Doc. 11/22). The new reference points values approved for the 3NO cod CPRS were the following: $B_{lim}$ = 60,000 t, $B_{isr}$ = 120,000 t, $F_{lim}$ = 0.30 and $B_{msy}$ = 248,000 t. Concerns were raised on the high uncertainty and the lack of confidence intervals of the reference points. The WGFMS-CPRS agreed that the values of $B_{isr}$ and $B_{msy}$ should be further reviewed by the Scientific Council and the Fisheries Commission.

The aim of this document is to revise the approved Fisheries Commission reference point values and provide their confidence intervals.

## Data

Data used in this document (1959-2009) were the available biological data and the results of the last approved NAFO assessment for 3NO cod (Power *et al.*, 2010). Catch and stock mean weights at age are presented in Table 1 and 2. Maturity ogive is showed in Table 3. Natural mortality was assumed constant by age and year and equal to 0.2.

The Partial Recruitment (PR) was calculated for each year as the F at age divided by the maximum F at age of each year (Table 4). The mean PR by age for the period 1959-2009 was calculated; these means were referenced to mean PR ages 4 to 6.

Partial recruitment, stock weight, catch weights and maturity vectors were calculated as long-term average (1959-2009). The reasons to choose the long term average is to capture the variability observed in the inputs to estimate the candidate for a long term reference points more than the usual three years average used in the medium term projections.

Many of the results are presented with box plots and the meaning of each part of the plot in this study are the following: The bold lines represent the median, the box represents the 25% and 75% of the distribution, the whiskers 1.5 times the length of the box away from the box and the points are extreme values.

Figure 1 presents the SSB and F assessment results and the Biological References Points (BRPs) approved in 2011 by the NAFO Fisheries Commission.

Most of the calculations were made with R 2.14.1 and the FLR 2.4 tools.

## Yield per Recruit (YPR) and Spawning per Recruit (SPR) reference points

*Reference points derived from yield-per-recruit analyses include $F_{max}$, the (fully-recruited) fishing mortality rate which produces the maximum yield per recruit; and $F_{0.1}$, the fishing mortality rate corresponding to 10% of the slope of the yield-per-recruit curve at the origin* (Gulland and Boerema, 1973). *The $F_{0.1}$ reference point was conceptualized as a biologically precautionary target relative to $F_{max}$: at $F_{0.1}$, catch per unit effort is not reduced substantially, but the fishing mortality rate is lower than $F_{max}$. Because the yield-per-recruit analyses only reflect schedules of mortality and weight at age in the catch, both $F_{max}$ and $F_{0.1}$ are reference points in the context of growth overfishing, not recruitment overfishing* (Gabriel and Mace, 1999).

*A wide variety of reference points have been derived from spawning-stock-biomass-per-recruit models. In isolation, spawning-stock-biomass-per-recruit analyses reflect schedules of mortality, maturity, and spawning weight at age for a cohort. Under conditions of no fishing mortality, 100% of a stock's spawning potential is obtained. As fishing mortality rates increase, spawning stock biomass per recruit decreases, as more spawning opportunities are lost over the lifetime of the cohort. The reduction in spawning stock biomass per recruit relative to the unfished level can be reflected as a percentage of the maximum spawning potential (MSP)* (Gabriel and Mace, 1999).

In the present analysis, the YPR reference points ($F_{max}$ and $F_{0.1}$) were estimated as well as the Spawning per Recruit (SPR) reference points for $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ of the SSB unfished level. For these reference points, biological uncertainty was incorporated in growth, maturation and in the fishery through variability in the partial recruitment. To incorporate the uncertainty, a bootstrap with 1000 iterations was carried out over the years to the whole period (1959-2009). Maturity, partial recruitment, stock and catch weights were bootstrapped together from the selected year range. The main reason to perform the bootstrap over the years was that more of the variability of weights, maturity, partial recruitment and recruitment should be related with the particular environmental conditions of each year. With this bootstrap data, a new mean was calculated for weights, maturity ogive and partial recruitment and YPR and SPR analyses were carried out with these new means.

Table 5 presents the values for the different fishing mortality YPR and SPR reference points estimated without uncertainty and the median, the 90 and 80 percentile values of the Bootstrap distribution. In all F references points the deterministic values are quite close to the median of the bootstrap distribution. $F_{max}$ values are the highest of the F BPRs estimated and $F_{0.1}$ and $F_{35\%}$ have very similar levels.

Figure 2 shows the YPR and SPR median curves for different F values. It also showed the $F_{max}$, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$ median values. It can be observed that the YPR curve presents a maximum quite well defined and that the SPR reference points estimated are around the $F_{0.1}$ value.

The deterministic equilibrium yield and SSB for all F reference points were calculated with the mean recruitment of the period (1959-2009) apply to the YPR and SPR estimated for the different F reference points. With uncertainty, for each bootstrap iteration, the mean recruitment of the bootstrap years was calculated and applied to the YPR and SPR. Table 6 presents the deterministic, median, 80% and the 90% percentile of the Bootstrap distribution for these values. In this case the deterministic values for the equilibrium SSB and yield are higher than the median of the bootstrap distribution.

## Maximum Sustainability Yield (MSY) Reference Points

Normally, when an age structure assessment provide a plausible set of stock and recruit pairs, the process of calculating the appropriate Maximum Sustainable Yield (MSY) reference points estimates should be based on combining the yield per recruit analysis and the stock recruit relationship. The method used in this study to estimated MSY reference points from the age structure assessment results was the proposed by Sissenwine and Shepherd (1987).

In the present study, the following stock-recruitment models were analyzed: Beverton-Holt, Ricker and Segmented Regression. It was used the FLR tools to fit these different models assuming log normal error distribution and to estimate the MSY biological references points. Table 7 presents the functions used and the deterministic fit parameter values for each model. Figure 3 presents the deterministic fit of the three models. To point out that the maximum of Ricker and Beverton-Holt models are outside of the observed levels of SSB. Ricker model has negative β parameter value that has not biological sense. In the case of Beverton-Holt the β parameter has a very big value with a very difficult biological explanation. Figure 3 is similar of the Shelton and Morgan (2011) Figure 1. It is the same for segmented regression and Beverton-Holt functions but is different for Ricker's one. The cause of these differences is the R version.

Figure 4 presents the FLR fit plots for Ricker model. This Figure has six plots. The upper left plot shows the stock-recruit pairs with the fitted stock recruitment relationship and a lowess smother to suggest an appropriate functional form. It can be observed that the Ricker and lowess fit are very similar and that the Ricker function has a convex curvature. The upper right plot shows the residuals plotted against year, and a clear residuals pattern can be observed in this case. This pattern in the residuals might indicate that average recruitment was either less or greater than expected, indicating either the wrong choice of model or a regime shift. The middle left plot presents the residuals with a lag of time 1, to identify autocorrelation, and it is clear in this case the residuals autocorrelation. The middle right plot is of the residuals against SSB. It seems that the errors do not present a clear pattern. Bottom left figure presents the observed residuals against their expected quantiles. It is obvious a systematic departure from the straight line, that indicates a violation of the assumptions of lognormal distribution of the errors. The bottom right plot presents the residuals against the fitted values as a check of the variance.

Figure 5 shows the likelihood profile of the Ricker's parameters. The likelihood profiles present for both parameters a clear maximum although the non biological sense of the parameter values.

Figure 6 presents the FLR fit plots for Beverton-Holt model. We can observe the same fit problems that in the Ricker fit: clear residuals patter, big autocorrelation, not log normal distribution of the errors.

Figure 7 shows the likelihood profile of the Beverton-Holt parameters. The Likelihood for both parameters has a flat profile with a not well defined maximum. This is a clear sign of the difficult to fit the data and to find a good value for the parameters, as many parameters values have a similar Likelihood.

Figure 8 presents the FLR fit plots for Segmented Regression model. We can observe the same fit problems that in the Ricker and Beverton-Holt fits: clear residuals pattern, big errors autocorrelation, not log normal distribution of the errors.

Figure 9 shows the likelihood profile of the Segmented Regression parameters. The likelihood profile for α parameter presents a well defined maximum but for the β parameter the likelihood profile is quite flat. This is a clear sign of the difficult to fit the data and to find a good value for this parameter, as many β parameter values have a similar Likelihood.

The goodness of fit was measured with the Pearson's correlation coefficient $r^2$ (Table 8). The fit is very poor in all the models as we can observe in the $r^2$ values of each model. Ricker model has the highest $r^2$ although is a small value. No S/R approach is strongly supported by the data and none of the models seems to be entirely adequate for describing the functional relationship between recruitment and SSB for 3NO cod. Model fits were also compared by assessing the Mean Absolute Error (MAE) and the Akaike information criterion (AIC).The AIC and MAE values (Table 8) of the different models are quite similar and the reasons to choose one of the models are weak and not clear. In this case, there is not strong justification to choose one among the several analyzed S/R relationships.

To include uncertainty in the stock recruitment relationships it was chosen a non-parametric bootstrap. This bootstrap consists in generating 1000 replicates where randomly sampled log residuals (with replacement) are added to the fitted recruitments in each year assuming log normal distribution for the residuals. The S/R is fitted again on these perturbed recruits against observed SSB. Following, the pairs of bootstrap parameters are used to estimate new values for MSY, $F_{msy}$, $B_{msy}$ etc. *This method has the advantage of simplicity and also, the range of variation of the input data is strongly driven by the signal in the observations, rather than being determined by a theoretical construct. The method is as well a natural way of caring for correlation among parameters* (Report of the Workshop on Implementing the ICES $F_{msy}$ Framework (WKFRAME-2), 2011). Much bootstrap iteration have problems to estimate the MSY reference points and they were discarded, making more iterations in order to have 1000 MSY reference point values.

Table 9 presents the deterministic $F_{msy}$, $SSB_{msy}$ and MSY estimations and the median, the 90 and 80 percentile values of the Bootstrap distribution for Ricker, Beverton-Holt and Segmented Regression Stock Recruitment relationships. The results for Ricker's case shows that in the deterministic solution it is not possible to found the values for these references points due to the impossibility with the data available to well determine the parameters values and the maximum of the function. In the Bootstrap, when it is forced to found a solution, much more iterations were needed to have 1000 values for the references points, and it found reasonably values but with a very large range. The median $SSB_{msy}$ (292,700 t) is in the order of the value found by Shelton and Morgan (2011) for the Loess smoother (247,681 t). For $F_{msy}$ and MSY the values found with Ricker and Loess smoother are very different; in the case of the $F_{msy}$ 0.152 and 0.30 and for the MSY 61,203 t and 119,148 t, respectively.

In Beverton-Holt, the values of $F_{msy}$ are quite small compare with the YPR references points. For $SSB_{msy}$ and MSY the deterministic and the Bootstrap values are very high and they have non biological sense due to the lack of fit of the available data.

The Segmented Regression presents similar deterministic and bootstrap results compare with the values obtained for $F_{max}$ in the equilibrium assuming mean recruitment.

## Discussion

Figure 10 shows fishing mortality YPR ($F_{max}$ and $F_{0.1}$), SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) reference points and Ricker, Beverton-Holt and Segmented Regression $F_{msy}$ as well as their correspondent SSB and Yield assuming mean recruitment in the case of the YPR and SPR references points and functional recruitment in the other cases. As it can be observed, the uncertainty is bigger for all the references points estimated with a S/R relationship. S/R relationship is generally a very uncertain relationship: many functional forms fit the data equally well (or bad), and with large residuals. By implication, the estimated reference points have wide confidence regions, and this is aggravated by additional uncertainty in the input data to per-recruit calculations (exploitation pattern, maturity-at-age and weights-at-age).

NAFO Fisheries Commission (NAFO/FC Doc. 11/22) adopted in 2011 the Interim 3NO cod CPRS. This document established the following cod 3NO reference points (Figure 1): $B_{lim}$ = 60,000 t, $B_{isr}$ = 120,000 t, $B_{msy}$ = 248,000 t and $F_{lim}$=$F_{msy}$ = 0.30. The base for some of these values was the SCR 11/39 by Shelton and Morgan.

Shelton and Morgan chose the Loess logs fit between the Ricker, Beverton-Holt, Segmented Regression, Loess, Loess logs and GAM to estimate the Biological References points (Figure 11). This election was based on Mean Absolute Errors (MAE) present in Table 10. The function chose to estimate the 3NO cod Biological Reference points has the biggest MAE of all, even which it was chosen to derive the MSY references points. It is well established that estimates of MSY-related reference points are strongly dependent on the specification of the S/R relationship, which itself is highly uncertain for a large number of fish stocks. In 3NO cod, there are not strong justifications to choose one among the several analyzed stock-recruit relationships. The election of one or other function to estimate $B_{msy}$ has a big implication as we can see in figure 10. For functions with similar MAE values, less than the chosen Loess log, we can find very different levels of $B_{msy}$.

The lack of fit of the S/R relationships is one of the mayor problems in 3NO cod. Figures 4 to 9 show these problems for all the functions analyzed: clear residuals pattern, big errors autocorrelation, not log normal distribution of the errors and problems in the fit parameters Likelihood profiles. Some of these problems were highlighted by Shelton and Morgan (2011): *No model or smoother has thus far been found to be entirely adequate for describing the functional relationship between recruitment and SSB for either 3LNO plaice or 3NO cod. In the case of 3NO cod there is pattern in the residuals with early data mostly above the value predicted by the smoother, falling to negative residuals in the early 1970s, some positive values in the mid to late 1970s, a big negative dip in residuals in the mid 1980s, followed by close to predicted values from the early 1990s onwards.*

To the lack of fit and to the residuals problems pointed out by Shelton and Morgan we would add the problem that the maximum of Ricker and Beverton-Holt Stock/Recruitment models are not defined in the observed SSB range. This last problem is a *quid* point to estimate $F_{msy}$, $B_{msy}$ and MSY as recognized the ICES Workshop on implementing the ICES Fmsy framework (ICES, 2010): *F targets which imply equilibrium SSB's outside the* *historic range should be looked at carefully, however it should be noted that where exploitation has historically been very high, this situation does not necessarily denote biological implausibility. The critical issue here is the fit to the S/R function. The fit to the Stock Recruit Relationship requires analysis (...). You could chose default function based on some statistical criteria for a measure of fit (e.g. AIC, BIC), but the fit needs to have biological plausibility. For example if the maximum in a dome shaped model is way out of the range of the observed biomass, there may be a problem.* In our opinion, when a stock recruitment function has a no well defined maximum of the recruitment in the observed SSB range, it should not be used as a basis for analyses of the Biological References points. In 3NO cod all the functions analyzed have this problem except the Segmented Regression.

The above cited workshop recommends when the S/R relationship has these problems estimating $F_{msy}$ using the segmented regression model, with constant recruitment above a threshold level, results in $F_{msy}$ being defined by the YPR estimate of $F_{max}$ or if $F_{max}$ is not well defined then $F_{0.1}$, $F_{35\%}$ or $F_{40\%}$ could be considered as a proxy for $F_{msy}$. To estimate the distribution of $B_{msy}$, it is recommended to use simulations incorporating biological uncertainty in the input parameters and from the simulation output to obtain a distribution of SSB values which should give the range of expected stock size when fishing under the $F_{msy}$ estimate. We try to apply this way to 3NO cod data. In this case the values found for the deterministic and bootstrap $F_{msy}$ of the segmented regression and for $F_{max}$ are very similar as it can see in Figure 10. The deterministic and the Bootstrap median values for both cases are very close to the approved value of $F_{lim}$ (0.30). These fishing mortality levels produce SSB levels (around 70,000 t) very similar to the approved $B_{lim}$ (60,000 t) as we can see in Tables 6 and 9 and Figure 10. This similarity in the Segmented Regression $F_{msy}$ and $F_{max}$ values for some stocks was previously explained by Mesnil and Rochet (2010). They found in two cod examples that $F_{msy}$ coincides with $F_{max}$, and suggested that varying the S/R relationship parameters has negligible effects on the value of $F_{msy}$. Due to the Segmented Regression β parameter Likelihood profile problems (Figure 9), it could be recommended the use of $F_{max}$ as proxy of $F_{msy}$ and $F_{lim}$.

The NAFO PA Framework specifies that $F_{target}$ should be chosen to ensure that there is a low probability (<20%) that F exceeds $F_{lim}$, and a very low probability (<5-10%) that biomass will decline below $B_{lim}$ within the foreseeable future (5-10 years). It could be proposed a value around $F_{0.1}$ (0.195) as a possible $F_{target}$. The reason to chose this value is that a small reduction in the YPR supposes a precautionary level of F that has a very low probability to be higher than $F_{lim} = F_{max}$ (less than 5%) and a very low probability (less than 5%) of SSB be less than $B_{lim}$ (60,000 t) as it can seen in Figure 2 and Tables 5 and 6.

A reasonable $B_{target}$ or $B_{msy}$ could be a value in the upper probability range of the $F_{0.1}$ equilibrium Biomass. NAFO defines a big probability as having the 20% of the risk. The 80% of probability of $F_{0.1}$ equilibrium Biomass gives a biomass around 120,000 t., there are 80% of probability that the $F_{0.1}$ equilibrium Biomass will be less than this target value (low risk tolerance).

The adopted Interim 3NO Cod Conservation Plan and Rebuilding Strategy established an intermediate stock reference point ($B_{isr}$) with the intention of delimiting the zone between $B_{lim}$ and $B_{msy}$. The value approved for $B_{isr}$ in 3NO cod was the double of $B_{lim}$ (120,000 t). There was not biological reason to choose this value. This new reference point seems to be similar than the ICES concept of a trigger point $MSYB_{trigger}$, which simply triggers action of reducing the exploitation from $F_{msy}$ or $F_{target}$ under the condition where the biomass moves out of the expected range. $MSYB_{trigger}$ is a biomass point which is expected with a low probability in a fully productive stock which is fished at $F_{msy}$ or $F_{target}$. $B_{trigger}$ should be selected as a biomass that is encountered with low probability if $F_{msy}$ is implemented. In the 3NO cod case, the level of biomass that has the 20% of the probability if we fish with $F_{0.1}$=$F_{target}$ is around 91,000 t. This value could be a good candidate for $B_{isr}$ if we take similar definition for $B_{isr}$ as the ICES $MSYB_{trigge}$: "biomass that has low probability if $F_{target}$ is implemented (intended low as 20% or less of probability)".

Figure 12 shows 2010 fishing mortality and SSB assessment results with the new proposed biomass and Fishing mortality Reference points. If we compare these values (Figure 12) with the approved by the Fisheries Commission (Figure 1) it seems that the new ones have more biological plausibility based on the available data, the analyzed period and the fishery history.

## Conclusions

The uncertainty is bigger for the references points estimated with S/R relationship than the YPR and SPR reference points as we can expected. The S/R relationship has a big uncertainty and this is aggravated by additional uncertainty in the input data to per-recruit calculations (exploitation pattern, maturity-at-age and weights-at-age).

The lack of fit of the S/R relationships is one of the mayor problems in 3NO cod. All the functions analyzed (Ricker, Beverton-Hold and Segmented regression) have clear fit problems: residuals pattern, big errors autocorrelation, not log normal distribution of the errors, problems in the fit parameters likelihood profiles and the maximum of the functions are not defined in the observed SSB range.

Due to these problems we propose to use YPR a SPR reference points as proxies of the MSY reference points in 3NO cod.

It could be recommended the use of $F_{max}$ (0.30) as proxy of $F_{msy}$ and $F_{lim}$ and as $B_{lim}$ a biomass level corresponding to the equilibrium $F_{max}$, around 60,000-70,000 tons.

It could be proposed a value around $F_{0.1}$ (0.195) as a possible $F_{target}$. The reason to chose this value is that supposes a precautionary level of F that has a very low probability to be higher than $F_{lim}$ and a very low probability of SSB be less than $B_{lim}$ (60,000 t). A reasonable $B_{target}$ could be a value in the upper probability range of the $F_{0.1}$ equilibrium Biomass. The 80% of probability of $F_{0.1}$ equilibrium Biomass gives a biomass around 120,000 t.

A good candidate for $B_{isr}$ could be 91,000 t. which is the level of biomass that has the 20% of the probability if we fish with $F_{0.1}$=$F_{target}$

## Acknowledgements

The authors would like to thank to Joanne Morgan and Peter Shelton for their ideas and comments.

## References

Clark W.G., 1991. Groundfish exploitation rates based on life history parameters. Canadian Journal of Fisheries and Aquatic Sciences Vol. 48: 741-750.

Clark W.G., 1993. The effect of recruitment variability on the choice of target level of spawning stock biomass per recruit. In Proceedings of the International Symposium on management strategies for exploited fish populations Alaska Sea Grant College Programme AK-SG-93- 02 1993: 233-246.

ICES, 2010. Report of the Workshop on Implementing the ICES Fmsy framework, 22-26 March 2010, Copenhagen, Denmark. ICES CM 2010/ACOM:54. 83 pp.

Gabriel, W. and P. Mace, 1999. A review of biological reference point in the context of the precautionary approach. NOAA. Tech. Memo, NMFS-F/SPO, 40: 34-44.

Goodyear C.P., 1993. Spawning stock biomass per recruit in fisheries management: Foundation and current use. In S.J. Hunt J.J. Smith, and D. Rivard [Eds]. Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences: 67-81.

Gulland, J.A. and L.K. Boerema, 1973. Scientific advice on catch levels. Fishery Bulletin 71(2): 325-335.

Mace P.M. and Sissenwine M.P., 1993 How much spawner per recruit is enough? In S.J. Hunt J.J. Smith, and D. Rivard [Eds] Risk evaluation and biological reference points for fisheries management. Canadian Special Publication of Fisheries and Aquatic Sciences: 100-118.

Mesnil, B. and Rochet, M.J., 2010. A continuous hockey stick stock-recruit model for estimating MSY reference points. ICES Journal of Marine Science, 67: 1780-1784. Publisher's official version: http://dx.doi.org/10.1093/icesjms/fsq055. Open access version: http://archimer.ifremer.fr/doc/00016/12735/

NAFO, 2003. Proposed NAFO Precautionary Approach Framework from Scientific Council. NAFO SCR Doc. 03/23, Serial No. N4900.

NAFO, 2004. Report of the Fisheries Commission 26th Annual Meeting, September 13-17, 2004. NAFO/FC Doc. 04/17, Serial No. N5067.

NAFO, 2007. Report of the Fisheries Commission, 24-28 September 2007, Lisbon, Portugal. NAFO/FC Doc. 07/24, Serial No. N5479.

NAFO, 2011. Report of the NAFO Scientific Council, 3-16 June, 2011. NAFO SCS Doc. 11/16, Serial No. N5930, 236 pp.

NAFO, 2011. Interim 3NO Cod Conservation Plan and Rebuilding Strategy. NAFO/FC Doc. 11/22, Serial No. N5956.

Power, S., J. Morgan, E.F. Murphy, J. Brattey and B. Healey, 2010. An Assessment of the Cod Stock in NAFO Divisions 3NO. NAFO SCR Doc. No. 10/42, Serial No. N5801.

Shelton, P. A., and M. J. Morgan, 2011. Further considerations regarding reference points, harvest control rules and rebuilding strategies for 3LNO American plaice and 3NO cod. NAFO SCR Doc. 11/039, Serial No. N5924.

Sissenwine, M.P. and J.G. Shepherd, 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aqua. Sc. 44: 913–918.

**Table 1.-** NAFO 3NO cod catch mean weights (kg) by age and year and mean weight (kg) by age for the 1959-2009 period.

| Year\Age | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1959** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1960** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1961** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1962** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1963** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1964** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1965** | 0.277 | 0.420 | 0.820 | 1.250 | 1.950 | 2.820 | 3.390 | 3.980 | 4.680 | 5.250 | 6.170 |
| **1966** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1967** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1968** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1969** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1970** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1971** | 0.277 | 0.480 | 0.900 | 1.350 | 2.140 | 3.160 | 4.210 | 6.340 | 7.690 | 8.460 | 10.240 |
| **1972** | 0.277 | 0.540 | 0.970 | 1.440 | 2.080 | 2.890 | 3.560 | 5.950 | 7.950 | 8.320 | 10.140 |
| **1973** | 0.277 | 0.570 | 1.000 | 1.430 | 2.190 | 3.630 | 4.630 | 6.250 | 9.560 | 11.170 | 13.990 |
| **1974** | 0.277 | 0.420 | 0.730 | 1.200 | 1.960 | 2.860 | 4.670 | 7.320 | 5.460 | 8.400 | 7.510 |
| **1975** | 0.277 | 0.380 | 0.890 | 1.280 | 2.130 | 3.140 | 4.160 | 5.530 | 6.740 | 5.270 | 7.090 |
| **1976** | 0.277 | 0.500 | 0.910 | 1.410 | 2.330 | 3.250 | 4.030 | 6.670 | 8.740 | 9.140 | 12.490 |
| **1977** | 0.277 | 0.570 | 1.000 | 1.480 | 2.480 | 3.510 | 4.740 | 7.170 | 8.810 | 11.700 | 11.470 |
| **1978** | 0.277 | 0.720 | 1.050 | 1.550 | 2.250 | 3.740 | 4.610 | 6.190 | 7.230 | 9.480 | 12.870 |
| **1979** | 0.277 | 0.650 | 0.980 | 1.390 | 2.090 | 2.870 | 3.700 | 4.750 | 7.150 | 7.980 | 10.110 |
| **1980** | 0.277 | 0.710 | 1.040 | 1.690 | 2.500 | 3.690 | 5.490 | 7.980 | 9.220 | 10.600 | 12.610 |
| **1981** | 0.277 | 0.900 | 1.270 | 1.840 | 2.690 | 3.550 | 5.330 | 7.130 | 9.100 | 9.010 | 10.150 |
| **1982** | 0.277 | 0.940 | 1.170 | 1.500 | 2.200 | 3.830 | 5.260 | 7.490 | 8.800 | 9.820 | 12.280 |
| **1983** | 0.277 | 0.850 | 1.170 | 1.870 | 2.630 | 3.800 | 5.200 | 6.270 | 8.080 | 8.990 | 11.010 |
| **1984** | 0.277 | 0.790 | 1.150 | 1.510 | 2.280 | 3.040 | 4.050 | 5.760 | 7.220 | 8.920 | 12.610 |
| **1985** | 0.277 | 0.480 | 0.860 | 1.370 | 2.050 | 3.250 | 4.650 | 6.620 | 8.320 | 9.150 | 11.130 |
| **1986** | 0.277 | 0.390 | 1.010 | 1.520 | 2.160 | 3.490 | 5.410 | 7.950 | 9.820 | 9.940 | 9.880 |
| **1987** | 0.277 | 0.490 | 0.820 | 1.300 | 1.830 | 2.890 | 4.760 | 7.260 | 8.950 | 9.850 | 12.590 |
| **1988** | 0.277 | 0.740 | 1.000 | 1.380 | 1.790 | 2.230 | 3.770 | 5.120 | 6.880 | 9.370 | 11.070 |
| **1989** | 0.277 | 0.510 | 0.970 | 1.600 | 2.240 | 3.270 | 4.610 | 7.080 | 8.310 | 9.470 | 12.250 |
| **1990** | 0.277 | 0.550 | 1.010 | 1.460 | 2.510 | 2.730 | 4.140 | 5.020 | 8.370 | 9.290 | 11.250 |
| **1991** | 0.277 | 0.550 | 0.850 | 1.590 | 2.300 | 3.830 | 5.560 | 7.530 | 9.040 | 11.980 | 13.980 |
| **1992** | 0.277 | 0.330 | 0.650 | 1.060 | 1.800 | 2.820 | 4.850 | 5.560 | 7.430 | 8.640 | 10.650 |
| **1993** | 0.277 | 0.360 | 0.780 | 1.350 | 1.840 | 2.820 | 4.110 | 5.870 | 7.760 | 8.790 | 8.670 |
| **1994** | 0.277 | 0.270 | 0.460 | 0.910 | 1.630 | 1.840 | 4.040 | 4.940 | 7.540 | 3.440 | 7.520 |
| **1995** | 0.277 | 0.421 | 0.750 | 1.210 | 2.030 | 2.290 | 2.080 | 6.600 | 6.220 | 6.409 | 8.028 |
| **1996** | 0.277 | 0.421 | 0.780 | 1.296 | 1.991 | 2.679 | 3.376 | 4.696 | 5.984 | 6.409 | 8.028 |
| **1997** | 0.277 | 0.421 | 0.780 | 1.296 | 1.991 | 2.679 | 3.376 | 4.696 | 5.984 | 6.409 | 8.028 |
| **1998** | 0.277 | 0.421 | 0.780 | 1.296 | 1.991 | 2.679 | 3.376 | 4.696 | 5.984 | 6.409 | 8.028 |
| **1999** | 0.277 | 0.496 | 0.936 | 1.592 | 2.070 | 2.227 | 2.832 | 3.994 | 6.045 | 6.730 | 7.379 |
| **2000** | 0.277 | 0.596 | 0.823 | 1.445 | 2.390 | 3.441 | 2.903 | 2.636 | 3.784 | 5.247 | 6.074 |
| **2001** | 0.277 | 0.584 | 1.085 | 1.383 | 2.070 | 4.058 | 5.217 | 5.324 | 5.514 | 7.510 | 8.600 |
| **2002** | 0.277 | 0.672 | 1.008 | 1.521 | 2.245 | 3.375 | 5.145 | 5.989 | 7.107 | 8.471 | 9.315 |
| **2003** | 0.260 | 0.669 | 0.939 | 1.401 | 2.021 | 3.013 | 4.104 | 7.626 | 7.736 | 8.521 | 9.227 |
| **2004** | 0.380 | 0.690 | 0.921 | 1.378 | 2.173 | 3.029 | 3.933 | 5.793 | 8.544 | 9.702 | 8.775 |
| **2005** | 0.360 | 0.488 | 1.407 | 2.459 | 3.427 | 3.952 | 4.938 | 5.905 | 9.298 | 10.278 | 11.417 |
| **2006** | 0.330 | 0.675 | 1.109 | 1.363 | 2.046 | 2.603 | 3.256 | 4.658 | 7.068 | 7.386 | 14.862 |
| **2007** | 0.260 | 0.615 | 1.005 | 1.387 | 2.525 | 2.899 | 4.711 | 5.156 | 6.749 | 6.666 | 8.394 |
| **2008** | 0.150 | 0.347 | 1.040 | 1.587 | 1.951 | 2.914 | 2.630 | 5.840 | 5.903 | 6.361 | 10.032 |
| **2009** | 0.200 | 0.458 | 0.648 | 1.307 | 2.158 | 2.677 | 3.802 | 4.547 | 8.203 | 7.511 | 8.810 |
| **mean 1959-2009** | 0.277 | 0.529 | 0.919 | 1.410 | 2.148 | 3.062 | 4.118 | 5.715 | 7.167 | 7.966 | 9.666 |

**Table 2.-** NAFO 3NO cod stock mean weights (kg) by age and year and mean weight (kg) by age for the 1959-2009 period.

| Year\Age | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1959** | 0.277 | 0.301 | 0.664 | 1.001 | 1.622 | 2.572 | 3.129 | 3.670 | 4.419 | 4.843 | 5.691 |
| **1960** | 0.277 | 0.301 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1961** | 0.277 | 0.301 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1962** | 0.277 | 0.301 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1963** | 0.277 | 0.301 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1964** | 0.277 | 0.301 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1965** | 0.277 | 0.287 | 0.587 | 1.012 | 1.561 | 2.345 | 3.092 | 3.673 | 4.316 | 4.957 | 5.691 |
| **1966** | 0.277 | 0.351 | 0.615 | 1.052 | 1.636 | 2.482 | 3.446 | 4.636 | 5.532 | 6.292 | 7.332 |
| **1967** | 0.277 | 0.351 | 0.657 | 1.102 | 1.700 | 2.600 | 3.647 | 5.166 | 6.982 | 8.066 | 9.308 |
| **1968** | 0.277 | 0.351 | 0.657 | 1.102 | 1.700 | 2.600 | 3.647 | 5.166 | 6.982 | 8.066 | 9.308 |
| **1969** | 0.277 | 0.351 | 0.657 | 1.102 | 1.700 | 2.600 | 3.647 | 5.166 | 6.982 | 8.066 | 9.308 |
| **1970** | 0.277 | 0.351 | 0.657 | 1.102 | 1.700 | 2.600 | 3.647 | 5.166 | 6.982 | 8.066 | 9.308 |
| **1971** | 0.277 | 0.338 | 0.657 | 1.102 | 1.700 | 2.600 | 3.647 | 5.166 | 6.982 | 8.066 | 9.308 |
| **1972** | 0.277 | 0.397 | 0.682 | 1.138 | 1.676 | 2.487 | 3.354 | 5.005 | 7.100 | 7.999 | 9.262 |
| **1973** | 0.277 | 0.504 | 0.735 | 1.178 | 1.776 | 2.748 | 3.658 | 4.717 | 7.542 | 9.423 | 10.789 |
| **1974** | 0.277 | 0.289 | 0.645 | 1.095 | 1.674 | 2.503 | 4.117 | 5.822 | 5.842 | 8.961 | 9.159 |
| **1975** | 0.277 | 0.246 | 0.611 | 0.967 | 1.599 | 2.481 | 3.449 | 5.082 | 7.024 | 5.364 | 7.717 |
| **1976** | 0.277 | 0.354 | 0.588 | 1.120 | 1.727 | 2.631 | 3.557 | 5.268 | 6.952 | 7.849 | 8.113 |
| **1977** | 0.277 | 0.420 | 0.707 | 1.161 | 1.870 | 2.860 | 3.925 | 5.375 | 7.666 | 10.112 | 10.239 |
| **1978** | 0.277 | 0.617 | 0.774 | 1.245 | 1.825 | 3.046 | 4.023 | 5.417 | 7.200 | 9.139 | 12.271 |
| **1979** | 0.277 | 0.514 | 0.840 | 1.208 | 1.800 | 2.541 | 3.720 | 4.679 | 6.653 | 7.596 | 9.790 |
| **1980** | 0.277 | 0.531 | 0.822 | 1.287 | 1.864 | 2.777 | 3.969 | 5.434 | 6.618 | 8.706 | 10.031 |
| **1981** | 0.277 | 0.789 | 0.950 | 1.383 | 2.132 | 2.979 | 4.435 | 6.256 | 8.522 | 9.114 | 10.373 |
| **1982** | 0.277 | 0.843 | 1.026 | 1.380 | 2.012 | 3.210 | 4.321 | 6.318 | 7.921 | 9.453 | 10.519 |
| **1983** | 0.277 | 0.731 | 1.049 | 1.479 | 1.986 | 2.891 | 4.463 | 5.743 | 7.779 | 8.894 | 10.398 |
| **1984** | 0.277 | 0.757 | 0.989 | 1.329 | 2.065 | 2.828 | 3.923 | 5.473 | 6.728 | 8.490 | 10.647 |
| **1985** | 0.277 | 0.331 | 0.824 | 1.255 | 1.759 | 2.722 | 3.760 | 5.178 | 6.923 | 8.128 | 9.964 |
| **1986** | 0.277 | 0.269 | 0.696 | 1.143 | 1.720 | 2.675 | 4.193 | 6.080 | 8.063 | 9.094 | 9.508 |
| **1987** | 0.277 | 0.343 | 0.566 | 1.146 | 1.668 | 2.498 | 4.076 | 6.267 | 8.435 | 9.835 | 11.187 |
| **1988** | 0.277 | 0.646 | 0.700 | 1.064 | 1.525 | 2.020 | 3.301 | 4.937 | 7.067 | 9.158 | 10.442 |
| **1989** | 0.277 | 0.362 | 0.847 | 1.265 | 1.758 | 2.419 | 3.206 | 5.166 | 6.523 | 8.072 | 10.714 |
| **1990** | 0.277 | 0.442 | 0.718 | 1.190 | 2.004 | 2.473 | 3.679 | 4.811 | 7.698 | 8.786 | 10.322 |
| **1991** | 0.277 | 0.506 | 0.684 | 1.267 | 1.832 | 3.101 | 3.896 | 5.583 | 6.737 | 10.014 | 11.396 |
| **1992** | 0.277 | 0.215 | 0.598 | 0.949 | 1.692 | 2.547 | 4.310 | 5.560 | 7.480 | 8.838 | 11.295 |
| **1993** | 0.277 | 0.318 | 0.507 | 0.937 | 1.397 | 2.253 | 3.404 | 5.336 | 6.569 | 8.081 | 8.655 |
| **1994** | 0.277 | 0.162 | 0.407 | 0.842 | 1.483 | 1.840 | 3.375 | 4.506 | 6.653 | 5.167 | 8.130 |
| **1995** | 0.277 | 0.309 | 0.450 | 0.746 | 1.359 | 1.932 | 1.956 | 5.164 | 5.543 | 6.951 | 5.255 |
| **1996** | 0.277 | 0.309 | 0.573 | 0.986 | 1.552 | 2.332 | 2.781 | 3.125 | 6.284 | 6.314 | 7.173 |
| **1997** | 0.277 | 0.309 | 0.573 | 1.005 | 1.606 | 2.310 | 3.007 | 3.982 | 5.301 | 6.193 | 7.173 |
| **1998** | 0.277 | 0.282 | 0.573 | 1.005 | 1.606 | 2.310 | 3.007 | 3.982 | 5.301 | 6.193 | 7.173 |
| **1999** | 0.277 | 0.386 | 0.628 | 1.114 | 1.638 | 2.106 | 2.754 | 3.672 | 5.328 | 6.346 | 6.877 |
| **2000** | 0.277 | 0.442 | 0.639 | 1.163 | 1.951 | 2.669 | 2.543 | 2.732 | 3.887 | 5.632 | 6.394 |
| **2001** | 0.277 | 0.444 | 0.805 | 1.067 | 1.730 | 3.115 | 4.237 | 3.931 | 3.813 | 5.330 | 6.717 |
| **2002** | 0.277 | 0.569 | 0.767 | 1.285 | 1.762 | 2.643 | 4.569 | 5.590 | 6.151 | 6.834 | 8.364 |
| **2003** | 0.260 | 0.571 | 0.795 | 1.188 | 1.753 | 2.600 | 3.722 | 6.264 | 6.807 | 7.782 | 8.841 |
| **2004** | 0.380 | 0.483 | 0.785 | 1.138 | 1.745 | 2.474 | 3.442 | 4.876 | 8.072 | 8.664 | 8.647 |
| **2005** | 0.360 | 0.324 | 0.985 | 1.505 | 2.173 | 2.931 | 3.868 | 4.819 | 7.340 | 9.371 | 10.525 |
| **2006** | 0.330 | 0.554 | 0.736 | 1.385 | 2.243 | 2.987 | 3.587 | 4.796 | 6.460 | 8.287 | 12.359 |
| **2007** | 0.260 | 0.473 | 0.824 | 1.240 | 1.855 | 2.435 | 3.502 | 4.097 | 5.607 | 6.864 | 7.874 |
| **2008** | 0.150 | 0.254 | 0.799 | 1.263 | 1.645 | 2.712 | 2.762 | 5.245 | 5.516 | 6.552 | 8.178 |
| **2009** | 0.200 | 0.427 | 0.474 | 1.166 | 1.851 | 2.285 | 3.329 | 3.458 | 6.921 | 6.658 | 7.486 |
| **mean 1959-2009** | 0.277 | 0.410 | 0.695 | 1.136 | 1.734 | 2.559 | 3.540 | 4.822 | 6.368 | 7.479 | 8.699 |

**Table 3.-**NAFO 3NO cod maturity ogive by age and year and mean by age for the 1959-2009 period.

| Year\Age | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1959 | | 0.008 | 0.023 | 0.055 | 0.051 | 0.589 | 0.886 | 0.981 | 0.997 | 1.000 | 1.000 |
| 1960 | | 0.003 | 0.039 | 0.116 | 0.251 | 0.304 | 0.886 | 0.981 | 0.997 | 1.000 | 1.000 |
| 1961 | | 0.000 | 0.017 | 0.173 | 0.425 | 0.657 | 0.781 | 0.981 | 0.997 | 1.000 | 1.000 |
| 1962 | | 0.001 | 0.001 | 0.082 | 0.517 | 0.807 | 0.916 | 0.967 | 0.997 | 1.000 | 1.000 |
| 1963 | | 0.006 | 0.010 | 0.023 | 0.321 | 0.846 | 0.959 | 0.984 | 0.996 | 1.000 | 1.000 |
| 1964 | | 0.001 | 0.027 | 0.100 | 0.322 | 0.712 | 0.966 | 0.993 | 0.997 | 0.999 | 1.000 |
| 1965 | | 0.000 | 0.005 | 0.116 | 0.553 | 0.906 | 0.929 | 0.993 | 0.999 | 1.000 | 1.000 |
| 1966 | | 0.001 | 0.001 | 0.023 | 0.387 | 0.932 | 0.995 | 0.986 | 0.999 | 1.000 | 1.000 |
| 1967 | | 0.013 | 0.007 | 0.010 | 0.104 | 0.753 | 0.993 | 1.000 | 0.997 | 1.000 | 1.000 |
| 1968 | | 0.001 | 0.040 | 0.082 | 0.145 | 0.359 | 0.936 | 0.999 | 1.000 | 0.999 | 1.000 |
| 1969 | | 0.000 | 0.009 | 0.114 | 0.543 | 0.746 | 0.730 | 0.986 | 1.000 | 1.000 | 1.000 |
| 1970 | | 0.000 | 0.003 | 0.066 | 0.287 | 0.940 | 0.981 | 0.929 | 0.997 | 1.000 | 1.000 |
| 1971 | | 0.000 | 0.001 | 0.028 | 0.358 | 0.556 | 0.995 | 0.999 | 0.984 | 0.999 | 1.000 |
| 1972 | | 0.027 | 0.000 | 0.010 | 0.218 | 0.814 | 0.795 | 1.000 | 1.000 | 0.997 | 1.000 |
| 1973 | | 0.001 | 0.075 | 0.004 | 0.102 | 0.732 | 0.972 | 0.924 | 1.000 | 1.000 | 0.999 |
| 1974 | | 0.000 | 0.008 | 0.194 | 0.293 | 0.558 | 0.964 | 0.996 | 0.974 | 1.000 | 1.000 |
| 1975 | | 0.003 | 0.002 | 0.053 | 0.415 | 0.978 | 0.934 | 0.996 | 1.000 | 0.992 | 1.000 |
| 1976 | | 0.002 | 0.019 | 0.022 | 0.272 | 0.676 | 1.000 | 0.994 | 1.000 | 1.000 | 0.997 |
| 1977 | | 0.001 | 0.014 | 0.098 | 0.227 | 0.713 | 0.860 | 1.000 | 0.999 | 1.000 | 1.000 |
| 1978 | | 0.001 | 0.008 | 0.093 | 0.382 | 0.792 | 0.943 | 0.948 | 1.000 | 1.000 | 1.000 |
| 1979 | | 0.015 | 0.013 | 0.073 | 0.425 | 0.779 | 0.980 | 0.991 | 0.982 | 1.000 | 1.000 |
| 1980 | | 0.003 | 0.070 | 0.114 | 0.429 | 0.841 | 0.953 | 0.998 | 0.999 | 0.994 | 1.000 |
| 1981 | | 0.002 | 0.024 | 0.275 | 0.552 | 0.877 | 0.974 | 0.991 | 1.000 | 1.000 | 0.998 |
| 1982 | | 0.003 | 0.016 | 0.146 | 0.658 | 0.922 | 0.985 | 0.996 | 0.998 | 1.000 | 1.000 |
| 1983 | | 0.000 | 0.016 | 0.122 | 0.547 | 0.907 | 0.991 | 0.998 | 0.999 | 1.000 | 1.000 |
| 1984 | | 0.001 | 0.003 | 0.073 | 0.539 | 0.895 | 0.980 | 0.999 | 1.000 | 1.000 | 1.000 |
| 1985 | | 0.002 | 0.006 | 0.026 | 0.270 | 0.908 | 0.984 | 0.996 | 1.000 | 1.000 | 1.000 |
| 1986 | | 0.002 | 0.013 | 0.041 | 0.205 | 0.637 | 0.988 | 0.998 | 0.999 | 1.000 | 1.000 |
| 1987 | | 0.006 | 0.019 | 0.087 | 0.236 | 0.713 | 0.893 | 0.999 | 1.000 | 1.000 | 1.000 |
| 1988 | | 0.000 | 0.033 | 0.157 | 0.399 | 0.691 | 0.960 | 0.975 | 1.000 | 1.000 | 1.000 |
| 1989 | | 0.005 | 0.003 | 0.170 | 0.637 | 0.823 | 0.942 | 0.996 | 0.995 | 1.000 | 1.000 |
| 1990 | | 0.017 | 0.038 | 0.044 | 0.549 | 0.943 | 0.970 | 0.992 | 1.000 | 0.999 | 1.000 |
| 1991 | | 0.008 | 0.065 | 0.244 | 0.405 | 0.878 | 0.994 | 0.996 | 0.999 | 1.000 | 1.000 |
| 1992 | | 0.000 | 0.056 | 0.216 | 0.727 | 0.909 | 0.977 | 0.999 | 0.999 | 1.000 | 1.000 |
| 1993 | | 0.000 | 0.012 | 0.304 | 0.522 | 0.956 | 0.993 | 0.996 | 1.000 | 1.000 | 1.000 |
| 1994 | | 0.004 | 0.015 | 0.283 | 0.765 | 0.813 | 0.994 | 1.000 | 0.999 | 1.000 | 1.000 |
| 1995 | | 0.008 | 0.042 | 0.584 | 0.927 | 0.960 | 0.946 | 0.999 | 1.000 | 1.000 | 1.000 |
| 1996 | | 0.023 | 0.068 | 0.495 | 0.992 | 0.998 | 0.994 | 0.986 | 1.000 | 1.000 | 1.000 |
| 1997 | | 0.013 | 0.154 | 0.406 | 0.928 | 1.000 | 1.000 | 0.999 | 0.996 | 1.000 | 1.000 |
| 1998 | | 0.017 | 0.108 | 0.584 | 0.864 | 0.992 | 1.000 | 1.000 | 1.000 | 0.999 | 1.000 |
| 1999 | | 0.001 | 0.103 | 0.524 | 0.916 | 0.983 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2000 | | 0.001 | 0.014 | 0.436 | 0.909 | 0.988 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2001 | | 0.007 | 0.028 | 0.168 | 0.838 | 0.989 | 0.998 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2002 | | 0.007 | 0.137 | 0.428 | 0.747 | 0.972 | 0.999 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2003 | | 0.016 | 0.160 | 0.791 | 0.951 | 0.977 | 0.996 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2004 | | 0.026 | 0.137 | 0.843 | 0.989 | 0.998 | 0.998 | 0.999 | 1.000 | 1.000 | 1.000 |
| 2005 | | 0.014 | 0.114 | 0.614 | 0.993 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2006 | | 0.030 | 0.061 | 0.384 | 0.872 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2007 | | 0.025 | 0.160 | 0.226 | 0.751 | 0.968 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2008 | | 0.023 | 0.094 | 0.542 | 0.567 | 0.936 | 0.993 | 1.000 | 1.000 | 1.000 | 1.000 |
| 2009 | | 0.023 | 0.105 | 0.295 | 0.880 | 0.855 | 0.986 | 0.999 | 1.000 | 1.000 | 1.000 |
| 2010 | | 0.023 | 0.105 | 0.354 | 0.628 | 0.979 | 0.964 | 0.997 | 1.000 | 1.000 | 1.000 |
| Mean (1959-2009) | 0.000 | 0.007 | 0.043 | 0.219 | 0.533 | 0.833 | 0.959 | 0.991 | 0.998 | 0.999 | 1.000 |

**Table 4.-** NAFO 3NO cod Partial Recruitment (PR) by age and year. The PR was calculated for each year as the F at age divided by the maximum F at age of each year. PR mean by age for the 1959-2009 and this mean reference to ages 4-6 are also presented.

| Year\Age | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1959 | 0.000 | 0.042 | 0.193 | 0.391 | 0.588 | 0.510 | 0.509 | 0.363 | 0.437 | 1.000 | 0.492 |
| 1960 | 0.000 | 0.051 | 0.239 | 0.601 | 0.458 | 0.496 | 0.723 | 0.428 | 0.336 | 1.000 | 0.526 |
| 1961 | 0.000 | 0.016 | 0.179 | 0.846 | 1.000 | 0.594 | 0.741 | 0.537 | 0.254 | 0.034 | 0.718 |
| 1962 | 0.000 | 0.026 | 0.165 | 0.210 | 0.357 | 0.860 | 0.687 | 1.000 | 0.831 | 0.790 | 0.726 |
| 1963 | 0.000 | 0.005 | 0.086 | 0.316 | 0.307 | 0.299 | 0.884 | 1.000 | 0.913 | 0.511 | 0.623 |
| 1964 | 0.000 | 0.093 | 0.461 | 0.578 | 0.480 | 0.291 | 0.352 | 0.526 | 1.000 | 0.145 | 0.412 |
| 1965 | 0.000 | 0.004 | 0.060 | 0.146 | 0.299 | 0.512 | 0.485 | 0.227 | 1.000 | 0.524 | 0.381 |
| 1966 | 0.000 | 0.002 | 0.077 | 0.191 | 0.347 | 0.336 | 0.678 | 0.417 | 1.000 | 0.367 | 0.444 |
| 1967 | 0.000 | 0.100 | 0.397 | 0.717 | 0.699 | 0.643 | 1.000 | 0.198 | 0.156 | 0.424 | 0.635 |
| 1968 | 0.000 | 0.169 | 0.548 | 0.867 | 1.000 | 0.823 | 0.651 | 0.380 | 0.269 | 0.126 | 0.714 |
| 1969 | 0.000 | 0.099 | 0.320 | 1.000 | 0.937 | 0.507 | 0.785 | 0.827 | 0.682 | 0.561 | 0.764 |
| 1970 | 0.000 | 0.030 | 0.260 | 0.328 | 0.661 | 0.528 | 0.588 | 0.484 | 0.365 | 1.000 | 0.565 |
| 1971 | 0.000 | 0.015 | 0.751 | 0.935 | 0.829 | 0.638 | 1.000 | 0.415 | 0.386 | 0.521 | 0.721 |
| 1972 | 0.000 | 0.001 | 0.381 | 0.654 | 1.000 | 0.928 | 0.525 | 0.199 | 0.242 | 0.197 | 0.663 |
| 1973 | 0.000 | 0.418 | 1.000 | 0.635 | 0.903 | 0.422 | 0.422 | 0.492 | 0.291 | 0.267 | 0.560 |
| 1974 | 0.000 | 0.169 | 0.600 | 1.000 | 0.912 | 0.697 | 0.761 | 0.710 | 0.842 | 0.818 | 0.770 |
| 1975 | 0.000 | 0.016 | 0.247 | 0.358 | 0.633 | 0.687 | 0.830 | 0.934 | 0.813 | 1.000 | 0.771 |
| 1976 | 0.000 | 0.222 | 0.750 | 1.000 | 0.670 | 0.419 | 0.459 | 0.343 | 0.449 | 0.212 | 0.473 |
| 1977 | 0.000 | 0.017 | 0.177 | 0.473 | 0.549 | 0.700 | 0.598 | 0.736 | 0.955 | 1.000 | 0.646 |
| 1978 | 0.000 | 0.075 | 0.422 | 0.718 | 0.700 | 0.607 | 0.634 | 1.000 | 0.980 | 0.687 | 0.735 |
| 1979 | 0.000 | 0.009 | 0.276 | 1.000 | 0.918 | 0.858 | 0.464 | 0.361 | 0.310 | 0.239 | 0.650 |
| 1980 | 0.000 | 0.069 | 0.397 | 0.904 | 1.000 | 0.991 | 0.825 | 0.537 | 0.632 | 0.463 | 0.838 |
| 1981 | 0.000 | 0.072 | 0.278 | 0.495 | 0.611 | 1.000 | 0.879 | 0.816 | 0.589 | 0.951 | 0.827 |
| 1982 | 0.000 | 0.032 | 0.216 | 0.327 | 0.332 | 0.347 | 0.786 | 0.923 | 0.893 | 1.000 | 0.597 |
| 1983 | 0.000 | 0.108 | 0.119 | 0.396 | 0.496 | 0.448 | 0.531 | 1.000 | 0.930 | 0.845 | 0.619 |
| 1984 | 0.000 | 0.003 | 0.090 | 0.265 | 0.556 | 0.590 | 0.540 | 0.488 | 1.000 | 0.520 | 0.543 |
| 1985 | 0.000 | 0.004 | 0.214 | 0.790 | 0.856 | 1.000 | 0.590 | 0.512 | 0.407 | 0.851 | 0.740 |
| 1986 | 0.000 | 0.039 | 0.252 | 0.667 | 1.000 | 0.734 | 0.662 | 0.651 | 0.641 | 0.375 | 0.762 |
| 1987 | 0.020 | 0.137 | 0.101 | 0.329 | 0.445 | 0.370 | 0.396 | 0.824 | 0.795 | 1.000 | 0.509 |
| 1988 | 0.023 | 0.030 | 0.094 | 0.465 | 1.000 | 0.847 | 0.426 | 0.492 | 0.771 | 0.725 | 0.691 |
| 1989 | 0.037 | 0.303 | 0.444 | 0.986 | 1.000 | 0.989 | 0.811 | 0.452 | 0.460 | 0.885 | 0.813 |
| 1990 | 0.049 | 0.194 | 0.626 | 1.000 | 0.668 | 0.309 | 0.357 | 0.318 | 0.313 | 0.214 | 0.413 |
| 1991 | 0.329 | 0.274 | 0.285 | 0.495 | 0.662 | 0.937 | 0.876 | 1.000 | 0.918 | 0.903 | 0.869 |
| 1992 | 0.013 | 0.471 | 1.000 | 0.734 | 0.693 | 0.721 | 0.596 | 0.652 | 0.675 | 0.855 | 0.665 |
| 1993 | 0.047 | 0.260 | 0.588 | 0.972 | 1.000 | 0.771 | 0.418 | 0.399 | 0.467 | 0.477 | 0.647 |
| 1994 | 0.000 | 0.522 | 1.000 | 0.414 | 0.504 | 0.527 | 0.122 | 0.070 | 0.024 | 0.000 | 0.000 |
| 1995 | 0.000 | 0.000 | 1.000 | 0.061 | 0.075 | 0.043 | 0.000 | 0.020 | 0.000 | 0.000 | 0.000 |
| 1996 | 0.068 | 0.232 | 0.677 | 0.763 | 0.818 | 0.732 | 1.000 | 0.937 | 0.933 | 0.559 | 0.000 |
| 1997 | 0.040 | 0.210 | 0.544 | 0.787 | 0.671 | 0.789 | 0.695 | 0.887 | 1.000 | 0.825 | 0.887 |
| 1998 | 0.005 | 0.114 | 0.384 | 0.617 | 0.703 | 0.655 | 0.700 | 0.618 | 0.699 | 1.000 | 0.815 |
| 1999 | 0.049 | 0.263 | 0.902 | 1.000 | 0.684 | 0.570 | 0.450 | 0.326 | 0.475 | 0.296 | 0.286 |
| 2000 | 0.003 | 0.143 | 0.395 | 1.000 | 0.264 | 0.145 | 0.198 | 0.118 | 0.070 | 0.040 | 0.075 |
| 2001 | 0.031 | 0.281 | 0.581 | 1.000 | 0.819 | 0.939 | 0.773 | 0.562 | 0.272 | 0.221 | 0.178 |
| 2002 | 0.539 | 0.669 | 0.866 | 0.888 | 1.000 | 0.728 | 0.641 | 0.459 | 0.243 | 0.132 | 0.143 |
| 2003 | 0.041 | 0.583 | 1.000 | 0.719 | 0.428 | 0.269 | 0.101 | 0.106 | 0.067 | 0.037 | 0.030 |
| 2004 | 0.029 | 0.267 | 0.914 | 1.000 | 0.656 | 0.469 | 0.378 | 0.157 | 0.328 | 0.192 | 0.137 |
| 2005 | 0.002 | 0.007 | 0.019 | 0.115 | 0.229 | 0.560 | 0.990 | 1.000 | 0.414 | 0.376 | 0.337 |
| 2006 | 0.052 | 0.273 | 0.711 | 1.000 | 0.765 | 0.172 | 0.122 | 0.022 | 0.062 | 0.000 | 0.000 |
| 2007 | 0.003 | 0.544 | 0.884 | 1.000 | 0.791 | 0.830 | 0.480 | 0.249 | 0.250 | 0.139 | 0.000 |
| 2008 | 0.000 | 0.005 | 0.231 | 0.795 | 0.696 | 1.000 | 0.282 | 0.361 | 0.841 | 0.485 | 0.731 |
| 2009 | 0.022 | 0.202 | 0.302 | 0.891 | 0.731 | 0.740 | 0.945 | 0.227 | 0.795 | 0.493 | 1.000 |
| Mean 1959-2009 | 0.028 | 0.155 | 0.445 | 0.663 | 0.675 | 0.619 | 0.595 | 0.525 | 0.558 | 0.515 | 0.532 |
| Ref to ages 4-6 | 0.046 | 0.260 | 0.749 | 1.116 | 1.135 | 1.042 | 1.001 | 0.883 | 0.939 | 0.867 | 0.895 |

**Table 5.-** YPR reference points ($F_{max}$ and $F_{0.1}$) and SPR reference points ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) estimated without uncertainty (via FLR) and the median, the 90 and 80 percentile values of the Bootstrap distribution.

| | $F_{max}$ | $F_{0.1}$ | $F_{30\%}$ | $F_{35\%}$ | $F_{40\%}$ |
|---|---|---|---|---|---|
| Deterministics | 0.296 | 0.193 | 0.232 | 0.200 | 0.173 |
| 5% | 0.275 | 0.180 | 0.221 | 0.190 | 0.164 |
| 10% | 0.280 | 0.183 | 0.224 | 0.193 | 0.166 |
| 50% | 0.296 | 0.193 | 0.231 | 0.199 | 0.172 |
| 90% | 0.314 | 0.204 | 0.239 | 0.206 | 0.178 |
| 95% | 0.319 | 0.207 | 0.242 | 0.208 | 0.180 |

**Table 6.-** Equilibrium SSB and yield in tons for the YPR reference points ($F_{max}$ and $F_{0.1}$) and SPR reference points ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) estimated without uncertainty (via FLR) and the median, the 90 and 80 percentile values of the Bootstrap distribution.

| | $B_{max}$ | $B_{0.1}$ | $B_{30\%}$ | $B_{35\%}$ | $B_{40\%}$ |
|---|---|---|---|---|---|
| Deterministics | 74615 | 121147 | 100892 | 118039 | 134480 |
| 5% | 48861 | 79678 | 66141 | 77207 | 88258 |
| 10% | 52556 | 85272 | 71513 | 83379 | 95261 |
| 50% | 65027 | 105793 | 88158 | 103022 | 117734 |
| 90% | 79869 | 129088 | 108068 | 125798 | 143898 |
| 95% | 83160 | 135347 | 112710 | 131415 | 150292 |

| | $Y_{max}$ | $Y_{0.1}$ | $Y_{30\%}$ | $Y_{35\%}$ | $Y_{40\%}$ |
|---|---|---|---|---|---|
| Deterministics | 35338 | 33607 | 34749 | 33815 | 32582 |
| 5% | 22621 | 21505 | 22187 | 21617 | 20791 |
| 10% | 24467 | 23260 | 24055 | 23430 | 22542 |
| 50% | 30920 | 29394 | 30386 | 29576 | 28452 |
| 90% | 38162 | 36250 | 37494 | 36531 | 35161 |
| 95% | 40344 | 38336 | 39605 | 38564 | 37057 |

**Table 7-** Stock Recruitment models as well as their functions and the values of the parameters for the deterministic fit assuming log normal error distribution.

| **Model** | **Functions** | $\alpha$ | $\beta$ **('000)** |
|---|---|---|---|
| Ricker | $\alpha SSB \exp(-\beta SSB)$ | 0.45432 | -0.00422 |
| Beverton-Holt | $\alpha SSB/(\beta + SSB)$ | 409257200 | 746226700 |
| Segmented Regression | $if\, SSB \le \beta\, then\, \alpha SSB\, else\, \alpha\beta$ | 0.56978 | 73.29918 |

**Table 8.-** NAFO 3NO Cod r square, Akaike information criterion (AIC) and Mean Absolute Error (MAE) of the stock recruitment fit for Ricker, Beverton-Holt and segmented regression models.

| | Ricker | B-H | S R |
|---|---|---|---|
| $r^2$ | 20.53 | 14.16 | 11.49 |
| AIC | 48.29 | 48.98 | 49.18 |
| MAE | 31.2 | 32.12 | 32.25 |

**Table 9.-** Deterministic $F_{msy}$, $SSB_{msy}$ and MSY estimation and the median, the 90 and 80 percentile values of the Bootstrap distribution assuming Ricker (R), Beverton-Holt (BH) and Segmented Regression (SR) Stock Recruitment relationship.

| | $F_{msy}$ R | $F_{msy}$ BH | $F_{msy}$ SR |
|---|---|---|---|
| Deterministics | * | 0.112 | 0.276 |
| 5% | 0.113 | 0.094 | 0.275 |
| 10% | 0.122 | 0.098 | 0.280 |
| 50% | 0.152 | 0.118 | 0.296 |
| 90% | 0.188 | 0.142 | 0.314 |
| 95% | 0.196 | 0.149 | 0.319 |

| | $SSB_{msy}$ R | $SSB_{msy}$ BH | $SSB_{msy}$ SR |
|---|---|---|---|
| Deterministics | * | 868500000000 | 73824 |
| 5% | 95568 | 123856 | 40161 |
| 10% | 119103 | 167361 | 46064 |
| 50% | 292700 | 24380433 | 65525 |
| 90% | 1586829 | 1347430255508 | 97156 |
| 95% | 3025103 | 1916476067916 | 117470 |

| | MSY R | MSY BH | MSY SR |
|---|---|---|---|
| Deterministics | * | 130040000000 | 31786 |
| 5% | 22707 | 22509 | 19343 |
| 10% | 25815 | 29661 | 21724 |
| 50% | 61203 | 3953417 | 31003 |
| 90% | 308959 | 204674458534 | 45577 |
| 95% | 564632 | 301822469529 | 55968 |

**Table 10.-** Mean absolute error (MAE) for different S/R models fit to data for 3NO cod. From Shelton and Morgan (SCR 11/39).

| | Beverton-Holt | Ricker | Segmented | Loess | Loess Logs | GAM |
|---|---|---|---|---|---|---|
| Cod | 32.1 | 32.1 | 32.3 | 31.1 | 33.7 | 32.8 |

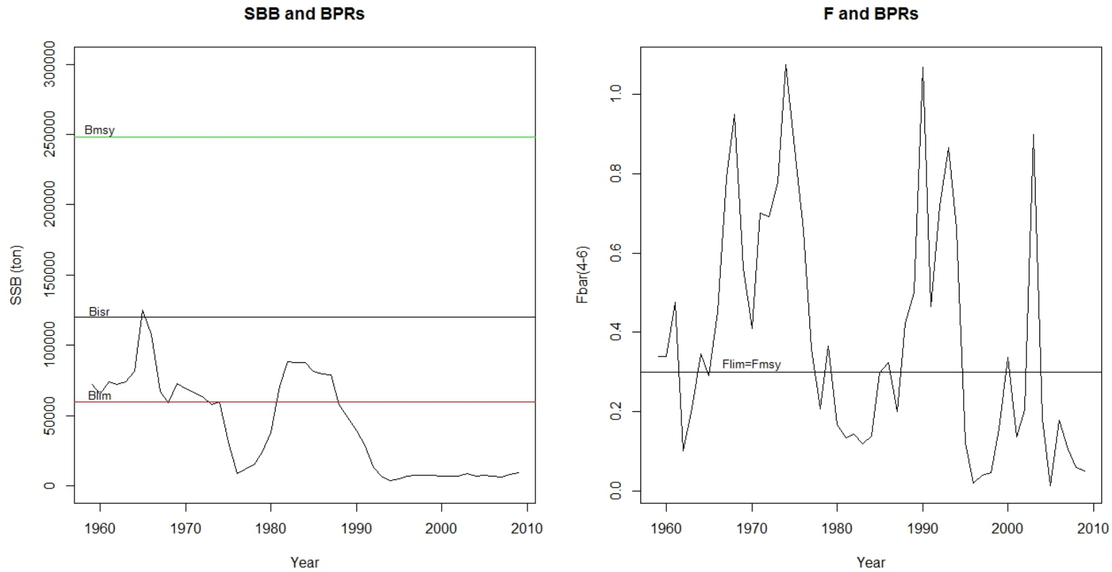


**Figure 1.-** NAFO 3NO Cod SSB and F from the 2010 assessment results and Biological References Points (BRPs) approved in 2011 by the Fisheries Commission.

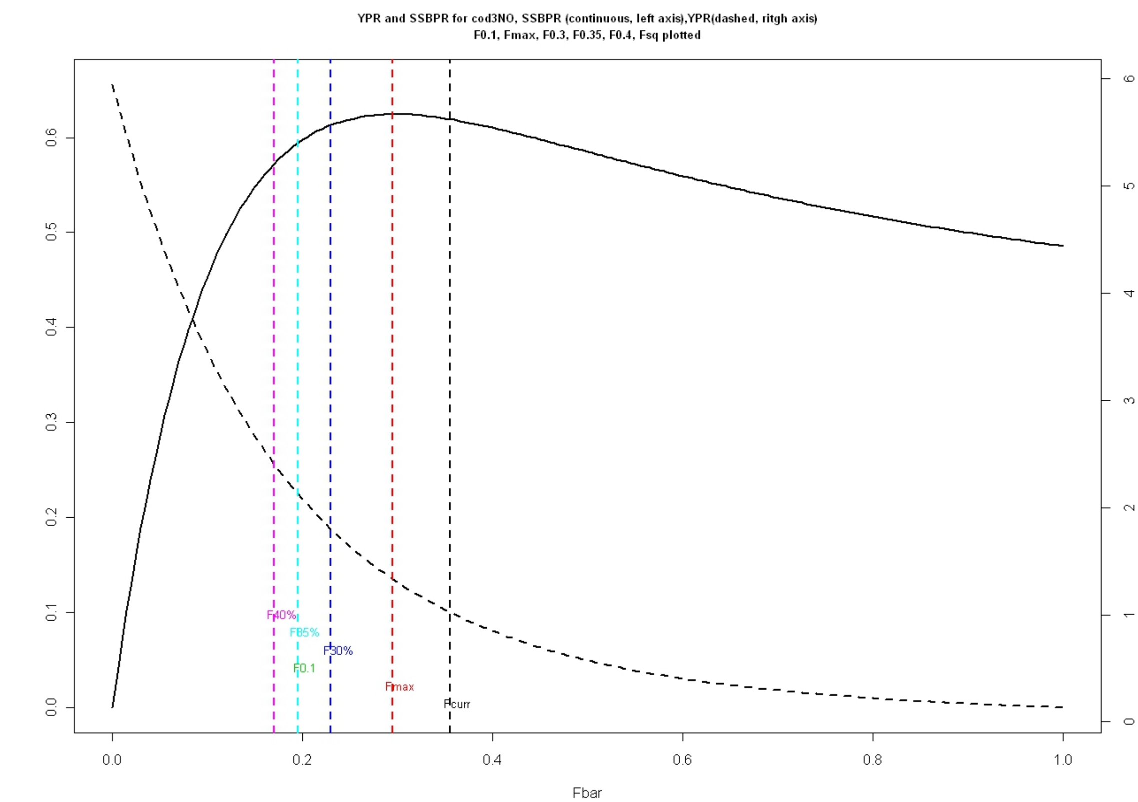


**Figure 2.-** Median Yield per Recruit (YPR) and SSB per Recruit (SPR) curve. The dash lines represent the median values of the Bootstrap distribution for the Biological references points ($F_{max}$, $F_{0.1}$, $F_{30\%}$, $F_{35\%}$ and $F_{40\%}$).

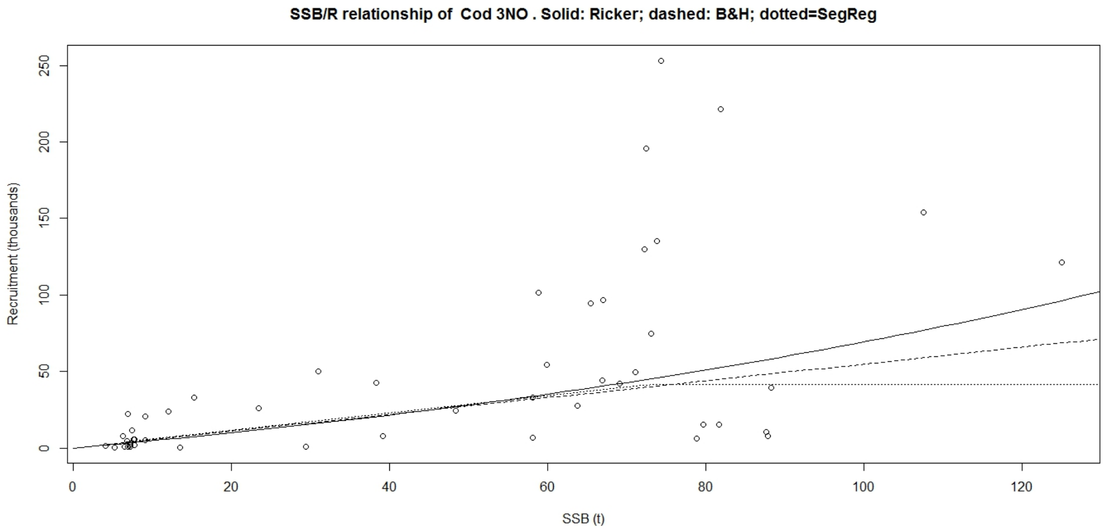


**Figure 3.-** Deterministic Ricker, Beverton-Holt and Segmented Regression stock recruitment models fit.

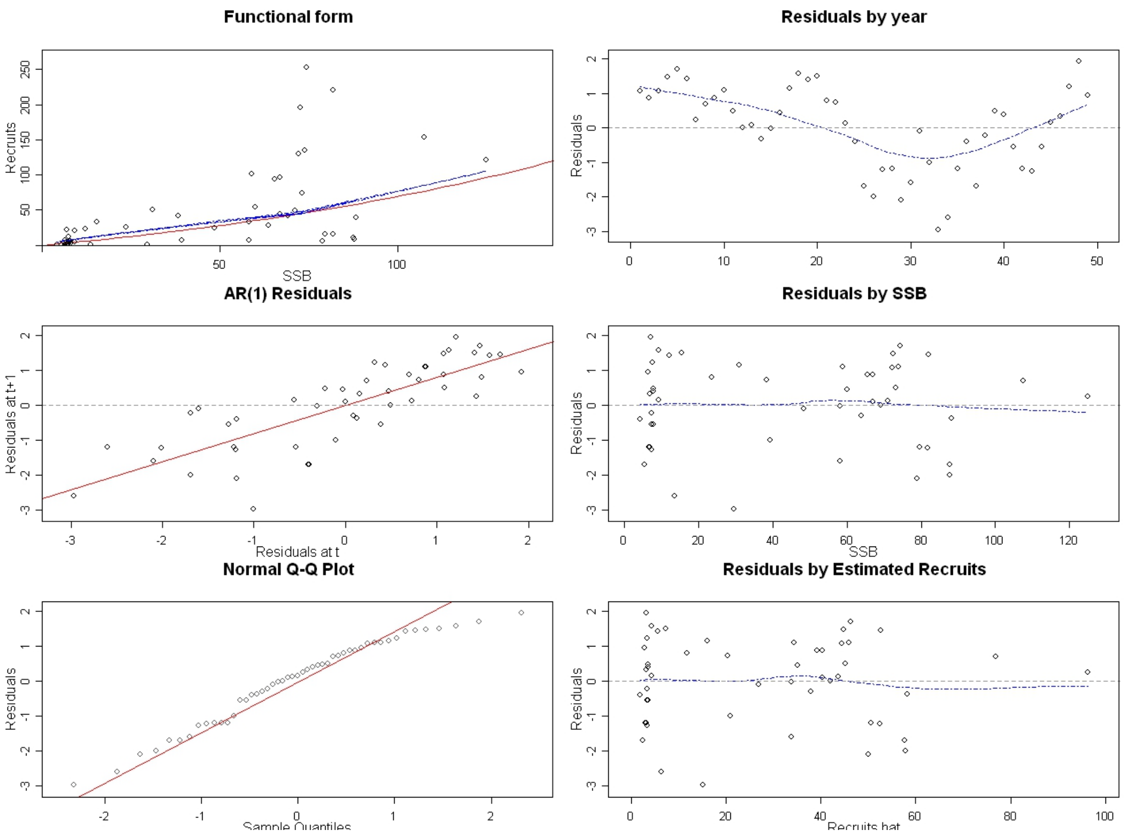


**Figure 4.-** Ricker fit FLR plots (see text).

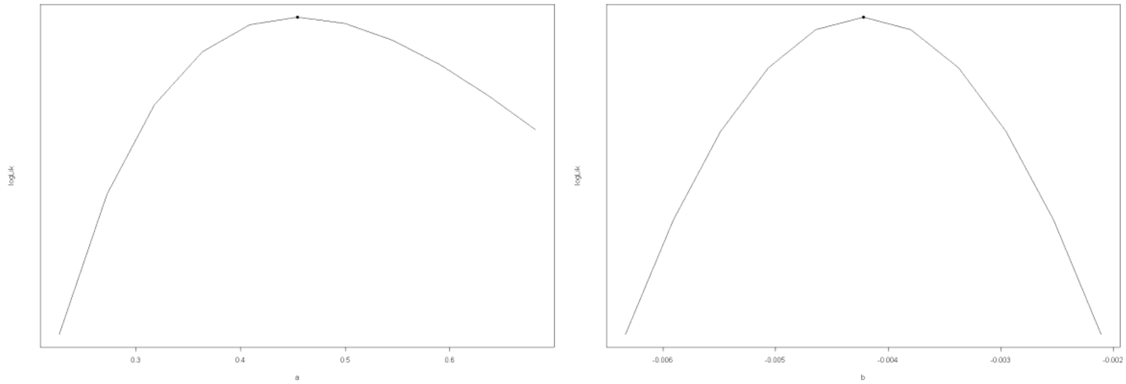

**Figure 5.-** Likelihood profiles of the Ricker's parameters deterministic fit.

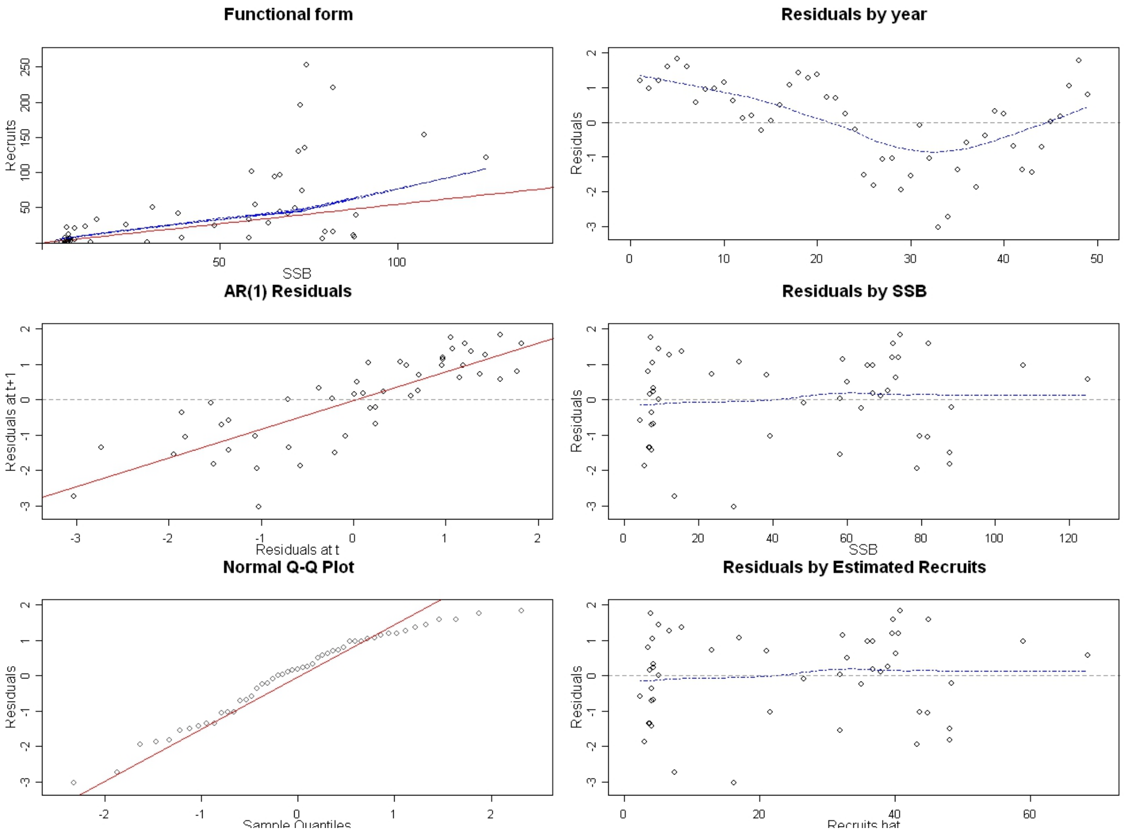


**Figure 6.-** Beverton-Holt fit FLR plots.

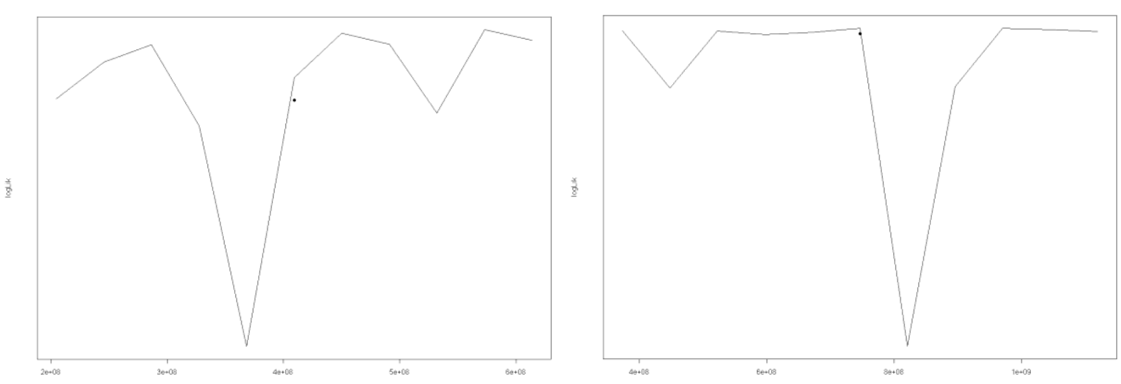

**Figure 7.-** Likelihood profiles of the B-H parameters deterministic fit.

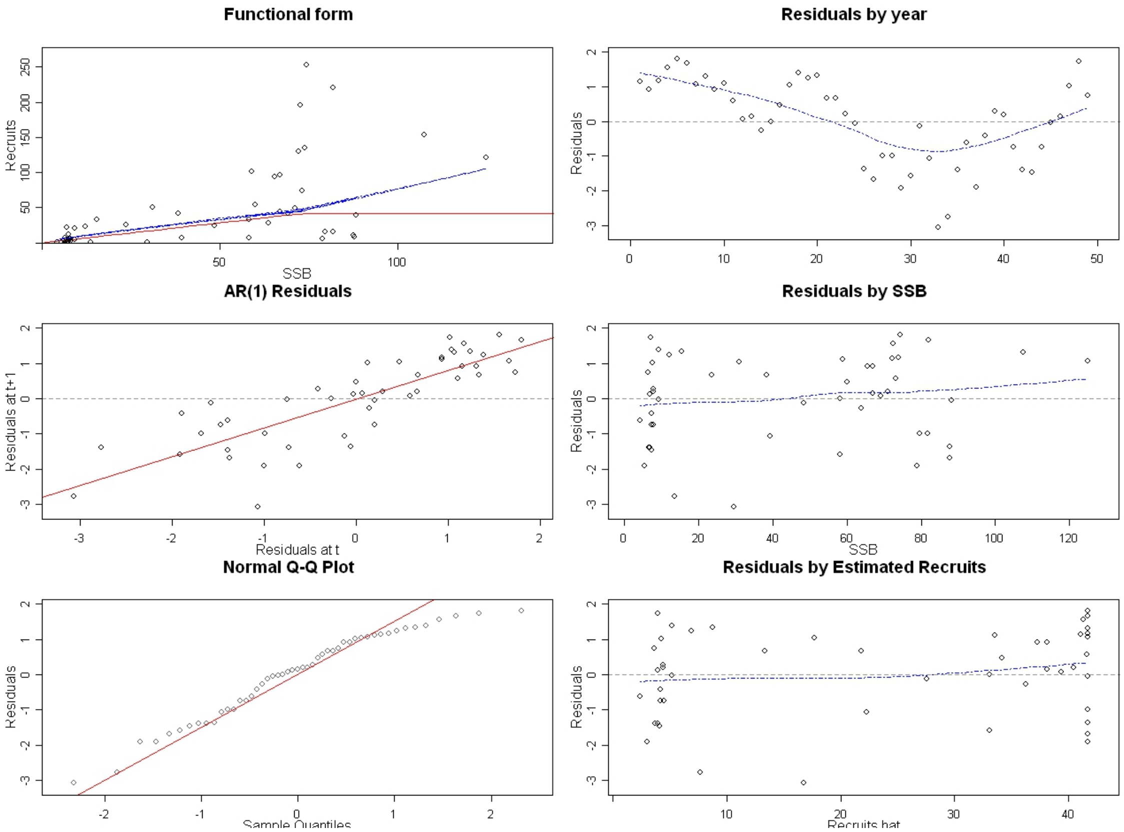


**Figure 8.-** Segmented Regression fit FLR plots

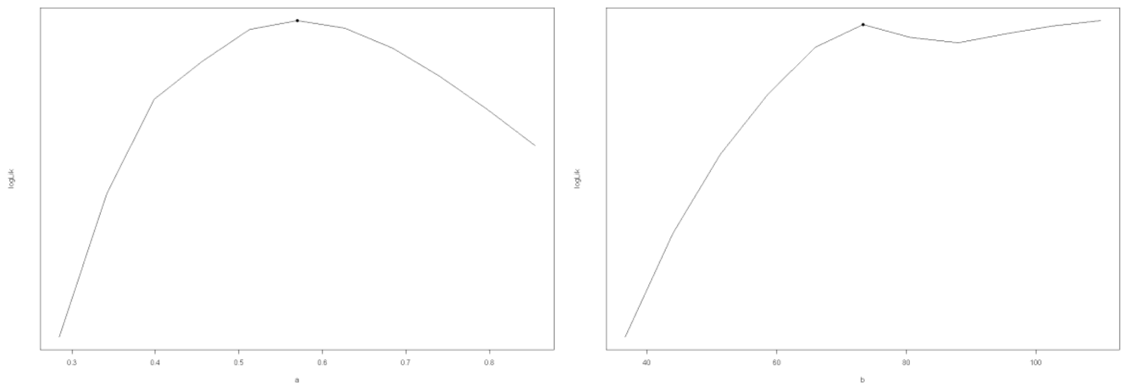

**Figure 9.-** Likelihood profiles of the segmented regression parameters deterministic fit.

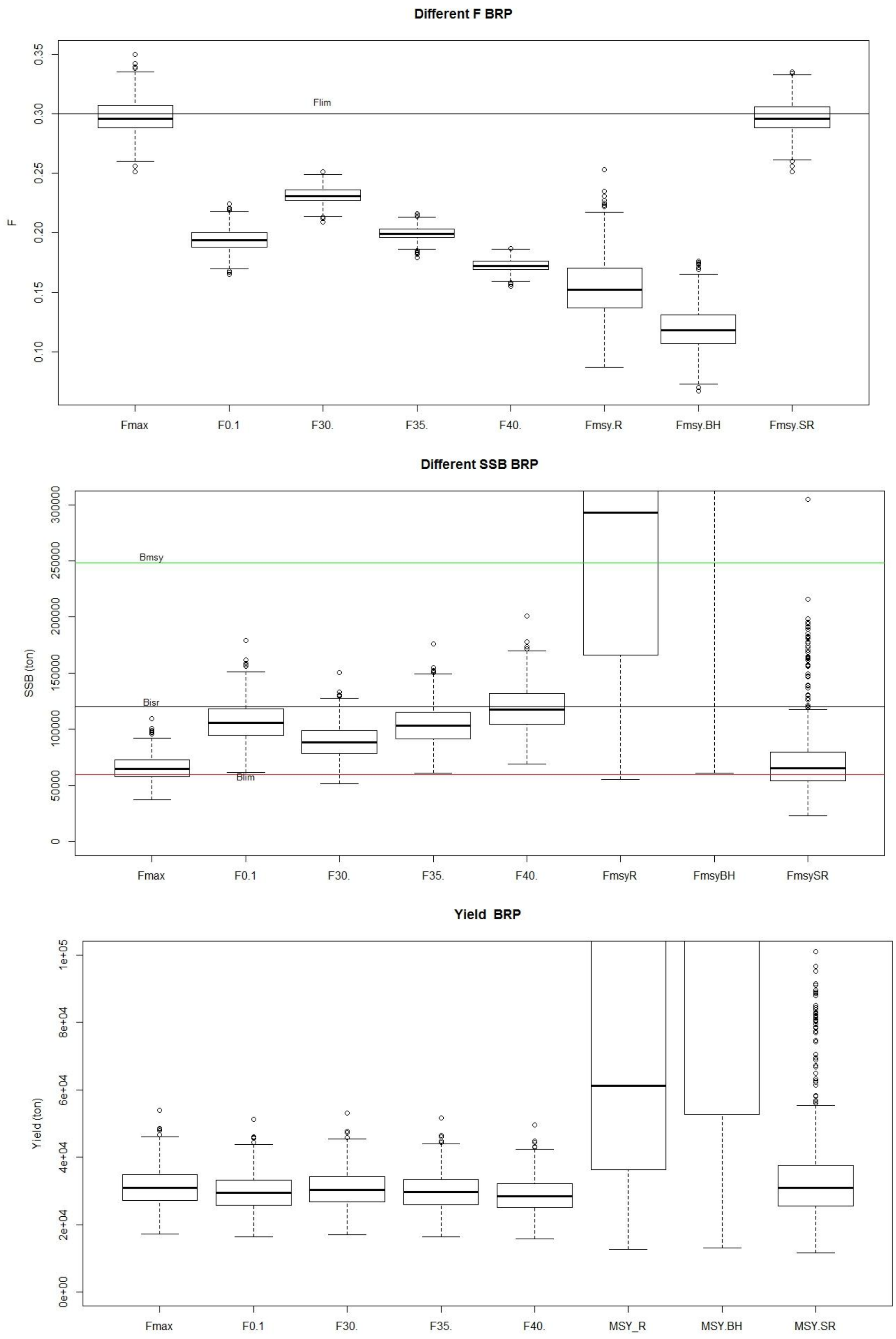


**Figure 10.-** Fishing mortality YPR ($F_{max}$ and $F_{0.1}$), SPR ($F_{30\%}$, $F_{35\%}$ and $F_{40\%}$) reference points and Ricker, Beverton-Holt and segmented regression $F_{msy}$ as well as their correspondent SSB and Yield assuming mean recruitment in the case of the YPR and SPR reference points and functional recruitment in the other cases. The lines represent the Biological References Points (BRPs) approved in 2011 by the Fisheries Commission.

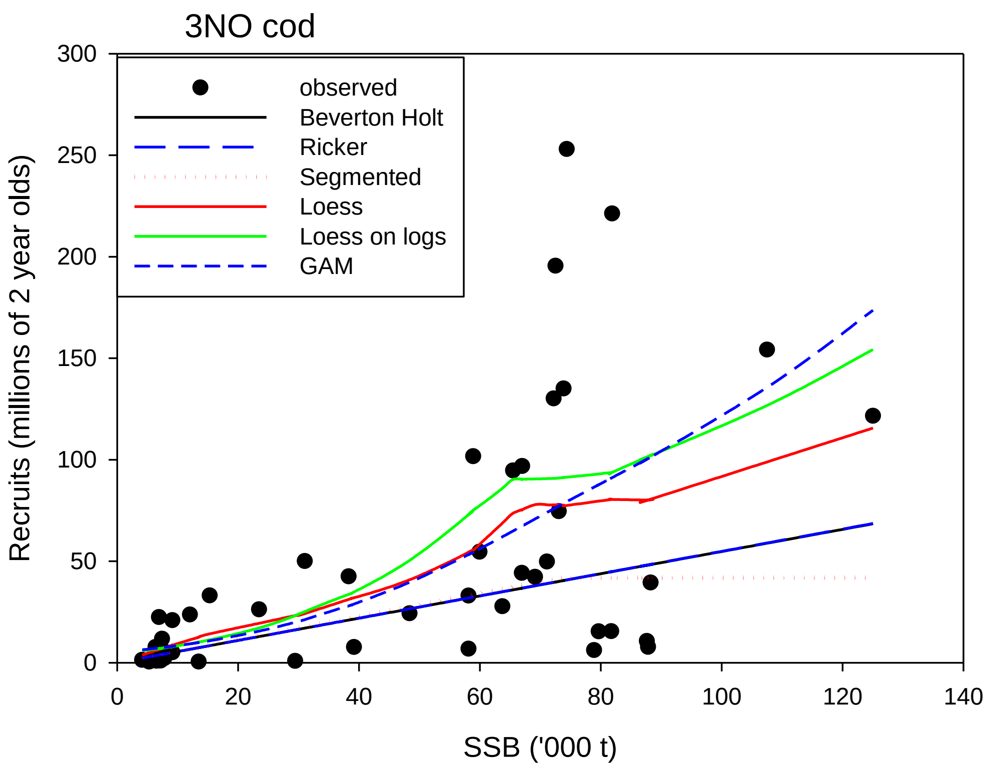


**Figure 11.-** Fit of alternative stock-recruit models to 3NO cod VPA estimates from the 2010 NAFO SC stock assessments. From Shelton and Morgan (SCR 11/39).

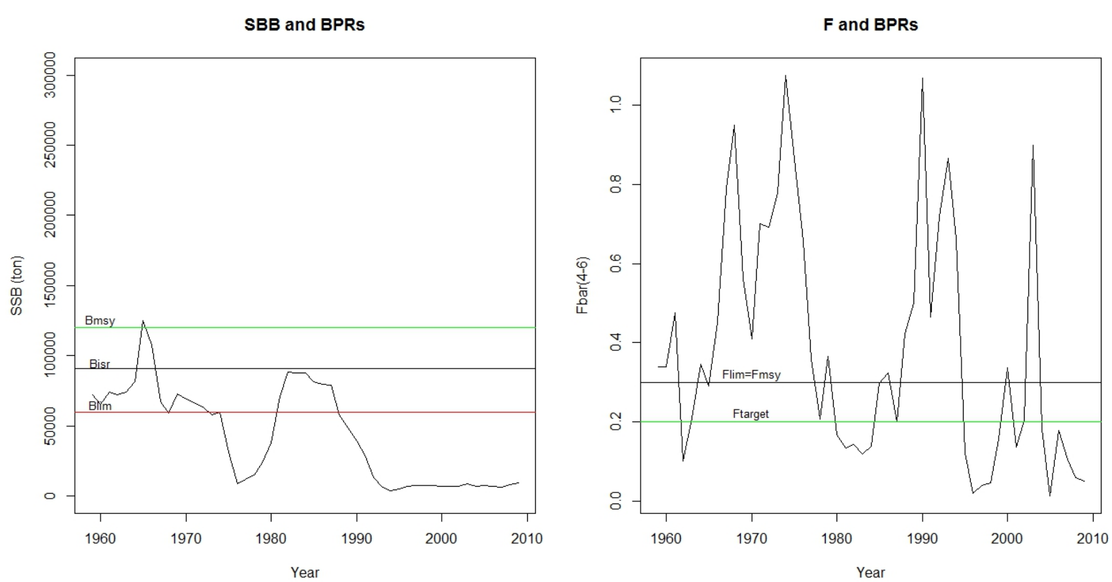


**Figure 12.-** NAFO 3NO cod SSB and Fishing mortality 2010 assessment results and the new propose values for the Biological References Points (BRPs).